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William B. White and Elizabeth L. White (USA): their contributions to karst hydrogeology discussed in an interview

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Introduction

Hydrogeologists and speleologists all over the world recognise William B. White (born 1934, USA) and Elizabeth L. White (born 1936, USA) for their achievements in the fields of karst hydrogeology and cave research, and have learned a great deal from their books, papers and lectures. It is also thanks to the Whites that many aspects of the specific hydrogeological characteristics of carbonate aquifers, such as turbulent flow in caves and conduits, are generally acknowledged today. Amazingly, both of them earned their merits in other subject areas and dedicated only a portion of their time to karst hydrogeology. However, cave and karst research is the topic on which they worked as a couple, at least partly, and their karst-related work is not only driven by scientific interest but also by personal interest and passion.

Elizabeth White is a civil engineer who worked not only on stormwater management and geological hazards, but also on cement, the beneficial use of fly ash, and other topics. Trained as an engineer, she was working on graduate hydrology research in the statistical characterization of drainage catchments of the Appalachian Mountains of the eastern US when she became intrigued by the behaviour of karst, and has had a passion for the subject ever since. In particular, she has made important contributions to the understanding of surface-water dynamics within karst-drainage systems.

William White is a researcher with universal scientific interest, who has spent most of his academic career at The Pennsylvania State University. Although citation statistics do not mean everything, his are impressive: he has authored or co-authored more than 400 papers, more than 200 in *Web of Science* (Thomson Scientific 2008); his most successful paper deals with Raman spectroscopy and has been cited over 1,000 times (Knight and White 1989). He has also investigated other spectroscopic techniques, crystal chemistry, glass and materials science, nuclear waste problems, and many other topics, and published his findings in about 60 different journals, often the best in their fields. The first karst hydrogeology paper on the list of his most-cited articles comes somewhere around rank 30. Still, he is often and rightly considered the "Grand Old Man" of cave and karst research in the US, and maybe worldwide.

During the workshop "Current Technology in Karst Hydrogeology and Water Resources" that took place at the Southwest University of China in Beibei, Chongqing, 7–14 October 2007, the authors had the opportunity to talk with the Whites about their life and research. A transcript of the complete interview is available (see Electronic supplementary material) and the interview itself can be seen on the Hydrogeologist Time Capsule website (http://timecapsule.iah.org). In the interview, which was both instructive and entertaining, the Whites were asked how they organise their scientific cooperation as a couple and the writing of joint papers (to which they responded "we didn't get a divorce over any of these"), and Elizabeth was asked how her husband could cope with such a wide range of research topics ("by not sleeping"). This profile focuses on the scientific contributions of William and Elizabeth White to karst hydrogeology (Fig. 1).

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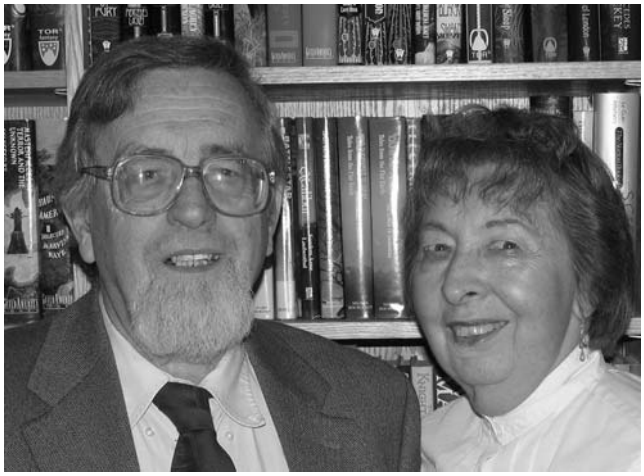

Fig. 1 William and Elizabeth White in front of the non-scientific wing of their library, in their home in Pennsylvania, USA

The importance of caves and conduits for groundwater flow

Although the foundations of karst geomorphology and hydrology were laid about a century ago and European researchers did pioneer work in this field, mainly in the Alps, Dinarides, and Jura Region, the role of conduits for groundwater flow was underestimated or ignored until a few decades ago. The Whites helped to bring the importance of caves and conduits to the attention of the American and international hydrogeology community.

William explained he was "trying to penetrate the conceptual framework that the traditional hydrogeologist has used for years and years and years: that porous media flow is the name of the game". He continued: "The idea, by the professional hydrologist in this 1960s time frame, was that caves were at most a little blip in the flow-field. Cavers were getting carried away by the fact they could go in there and splash around in the water but really back in the rock there was this uniform flow-field moving through the mass of the rock and the cave itself was just a blip, a small distortion at best, and of no particular importance. Victor Schmidt and I wrote a paper back in 1966, essentially trying to establish that most of the water in this drainage basin was moving through the caves."

This was probably the first paper in *Water Resources Research* about caves (White and Schmidt 1966). Other early, enduring, and influential works on karst hydrogeology include the development of conceptual models for limestone aquifers (White 1969) and one of the first studies to look at the time-dependence of karst spring water chemistry as a hydrogeological tool (Shuster and White 1971). William White's efforts to make speleological research socially acceptable in the scientific community are also documented in a paper about 'the cave environment' published in *Science* (Poulson and White 1969).

Elizabeth made her first great contribution to karst hydrogeology during her Master's thesis, when she analysed a series of watersheds in Pennsylvania, USA and noticed that karstic basins behaved completely different than all of the others, which were mostly underlain by shale and sandstone. She discovered that peak floods in karstic basins tend to be much more subdued because water storage in caves and karst aquifers clips the tops off the hydrographs, a recognition that was published in the *Journal of Hydrology* (White and Reich 1970). Other papers followed, in which she continued to transfer concepts from surface hydrology to the karst and cave environment such as a paper about 'channel hydraulics of free-surface streams in caves' that she prepared together with her husband (White and White 1970). Also, as a practicing engineer, she was confronted with the specific nature of limestone terrains and the associated hazards such as the collapse of cavities, often overlooked by conventional engineers without experiences in karst research and caving.

In 1988, William published his textbook on the *Geomorphology and Hydrology of Karst Terrains*, which is still a standard reference (White 1988). Only one year later, the two Whites published the edited volume *Karst Hydrology: Concepts from the Mammoth Cave Area*, which also helped to make hydrogeologists aware of the importance of caves for groundwater flow (White and White 1989). These books amalgamate the practical field experiences of cavers and the quantitative approach of a natural scientist and an engineer. Two other volumes about caves and karst science came out only recently, illustrating that the concept of 'retirement' does not apply to the Whites (Culver and White 2005; White and Culver 2007). However, William has reduced his 17 research fields to a more manageable 15.

Selected research highlights: limestone dissolution and sediment transport

It is beyond the scope of this profile to summarise and evaluate all contributions that the Whites have made to karst research, including papers about specific caves and karst regions in the USA and worldwide, karst geomorphology, processes of cavern breakdown and sinkhole collapse, soils on karst, and other topics. Among the various research topics in the field of karst hydrogeology, two aspects were selected that had a great influence on further research and that can still provide inspiration for future hydrogeological research.

The first is limestone dissolution kinetics. At first glance to non-practitioners of the field, this does not seem to be directly related to hydrogeology, but in fact it is: flowing groundwater charged with CO_2 and thus undersaturated with calcite, creates dissolutional conduits which in turn act as the principal flowpaths for groundwater. However, in the late 1950s, the understanding of limestone dissolution kinetics identified a problem that confounded karst scientists for a number of years: How can undersaturated water enter into fractured limestone without getting saturated rapidly? In other words, how can caves exist? William White found a first answer to this question: Water in contact with limestone rapidly reaches

a saturation level of about 80%, but after that point, the dissolution rate drops dramatically and finally becomes very slow. Therefore, slightly undersaturated water can actually enter deep into the limestone and cause initial karstification, and thus create initial groundwater flowpaths (White 1977; Rauch and White 1977). Later, other researchers continued to work on this problem and developed sophisticated models to simulate the process of speleogenesis and groundwater flow through evolving conduit networks.

The second topic, on which William is still actively working today, is the transport of sediments through karst systems. The Whites were among the first to investigate the dynamics of sediment transport in caves (White and White 1968) and they also recognised the importance of thresholds for karst hydrogeology: there is a threshold when a limestone fracture transforms into a conduit aquifer; there is a threshold between laminar flow and turbulent flow; and there are thresholds when the aquifer starts to transmit clastic sediments (Herman et al. 2008). Different types of contaminants are associated with sediments. Conduit sediments can act as reservoirs for heavy metals (Vesper and White 2004) and the highest heavy metal loads in karst spring waters can thus be observed during storm flow (Vesper and White 2003). Dense nonaqueous phase liquids (DNAPLs) also tend to accumulate in cave sediments from which they are remobilised and transported to the spring during floods (Loop and White 2001). The importance of thresholds and the role of sediments for contaminant transport and attenuation are among the topics where William sees the need for further research in the field of karst hydrogeology (White 2002).

Advice to the younger generation

The Whites were also asked for their advice to the younger generation, and William immediately answered, “The first is not to pay any attention to your professors.” More specifically, he advised that “the major breakthrough occurs when someone with a very young brain sees the world differently than all of these distinguished people with old brains.” However, the Whites are an impressive example of distinguished people with young brains, and they continue to provide inspiration for a younger generation of researchers.

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